SUPERGEN Wind
2011 General Assembly

How are we going to make offshore wind farms more reliable?

Peter Tavner

20th March 2011, Durham University

Durham University
School of Engineering and Computing Sciences

Summary

- **This research addresses issues of raising offshore wind farm Availability and lowering Cost of Energy**
- **What are we monitoring**
- **What reliability and availability are we getting**
- **What is it going to be like offshore**

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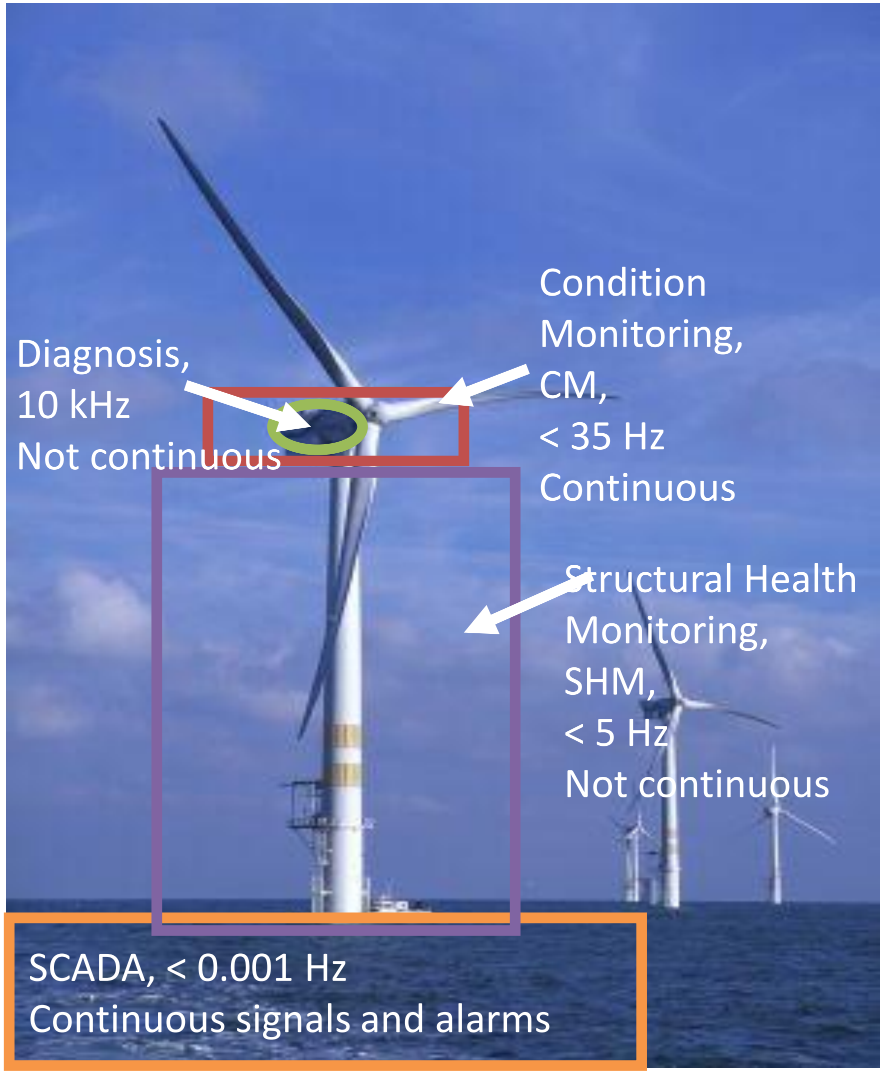
SCADA & Condition Monitoring in Context



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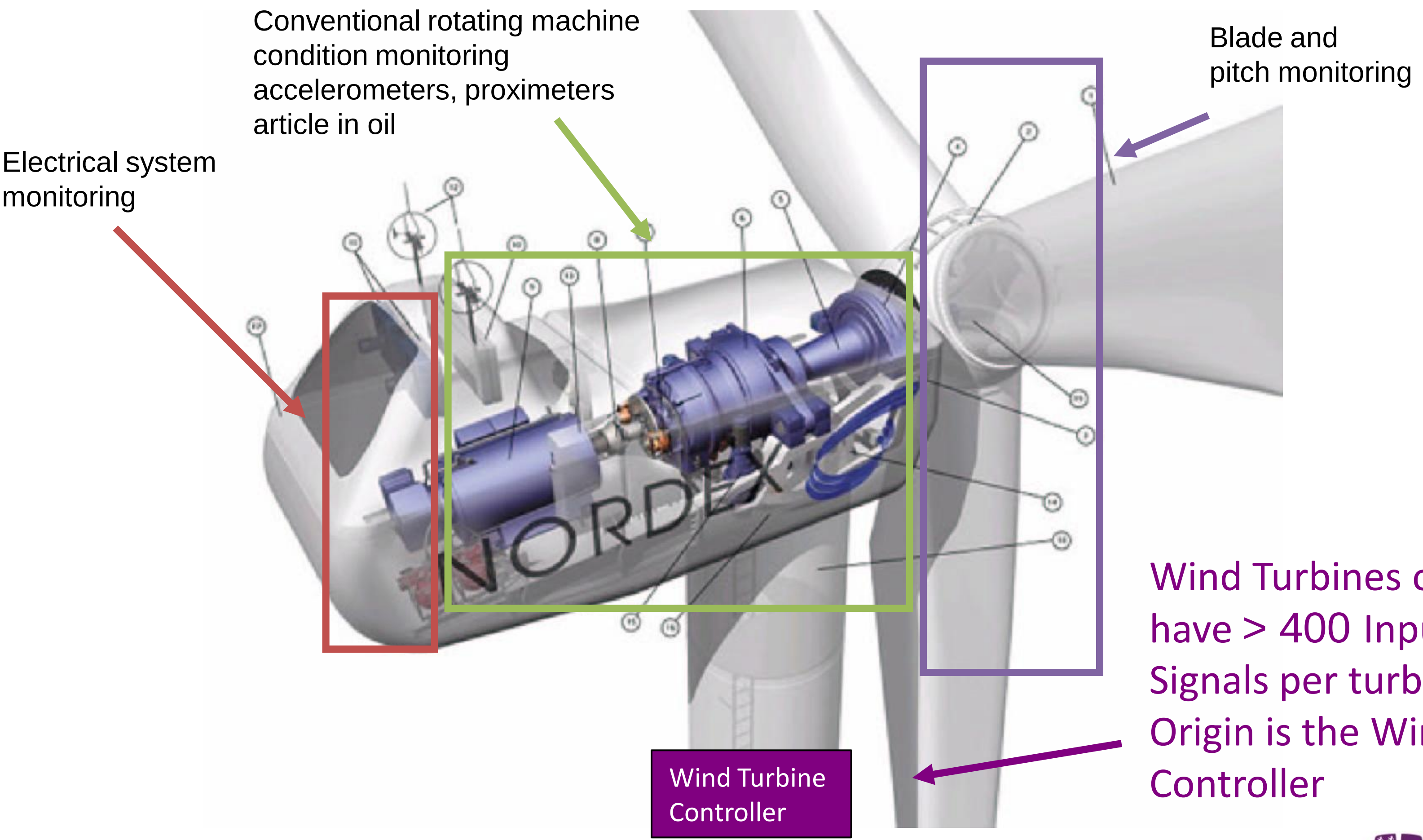
SCADA & Condition Monitoring in Context



Wind Turbines of >2 MW have > 400 Input/Output Signals per turbine.
Origin is the Wind Turbine Controller

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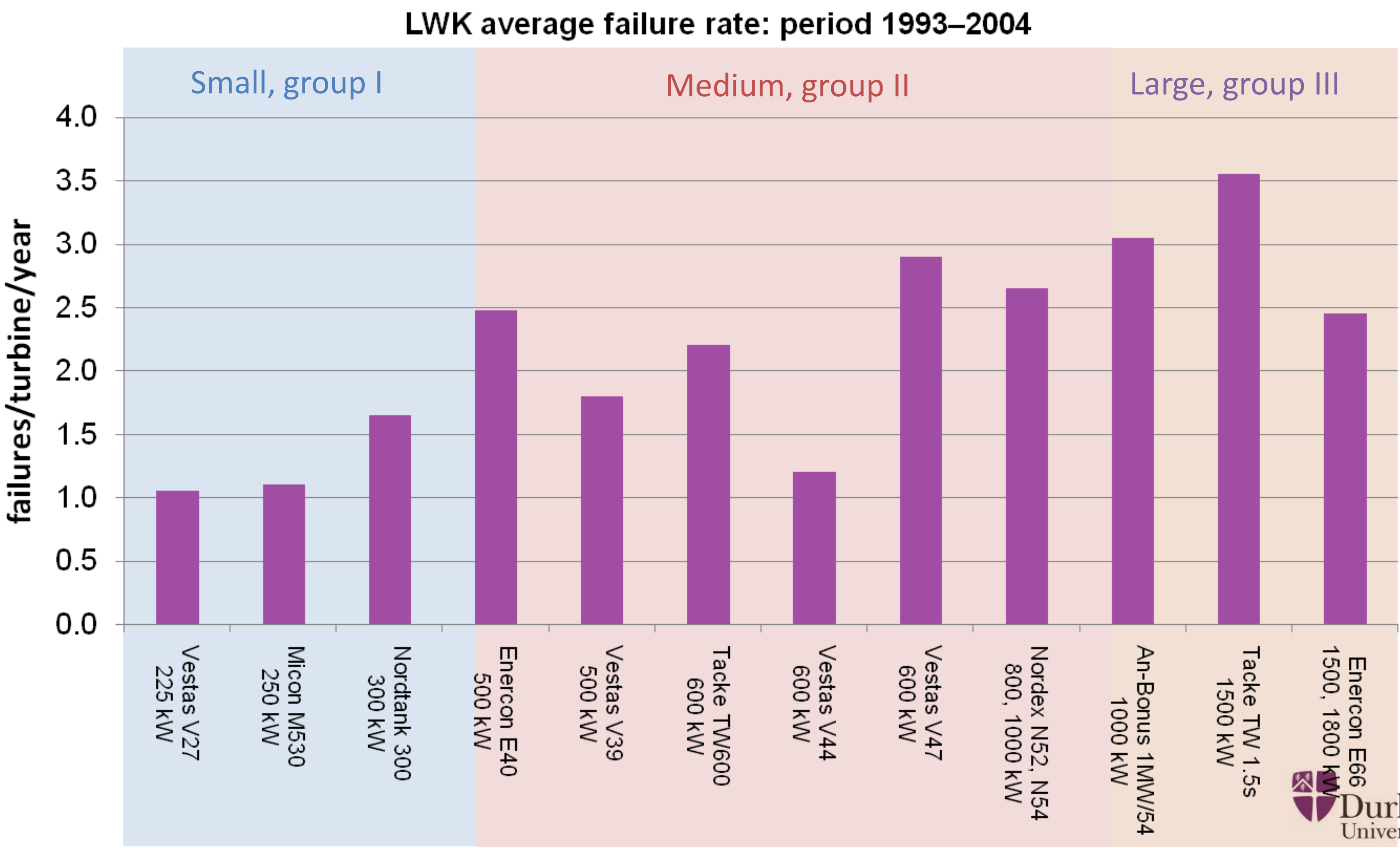
Reliability & Size Onshore, EU



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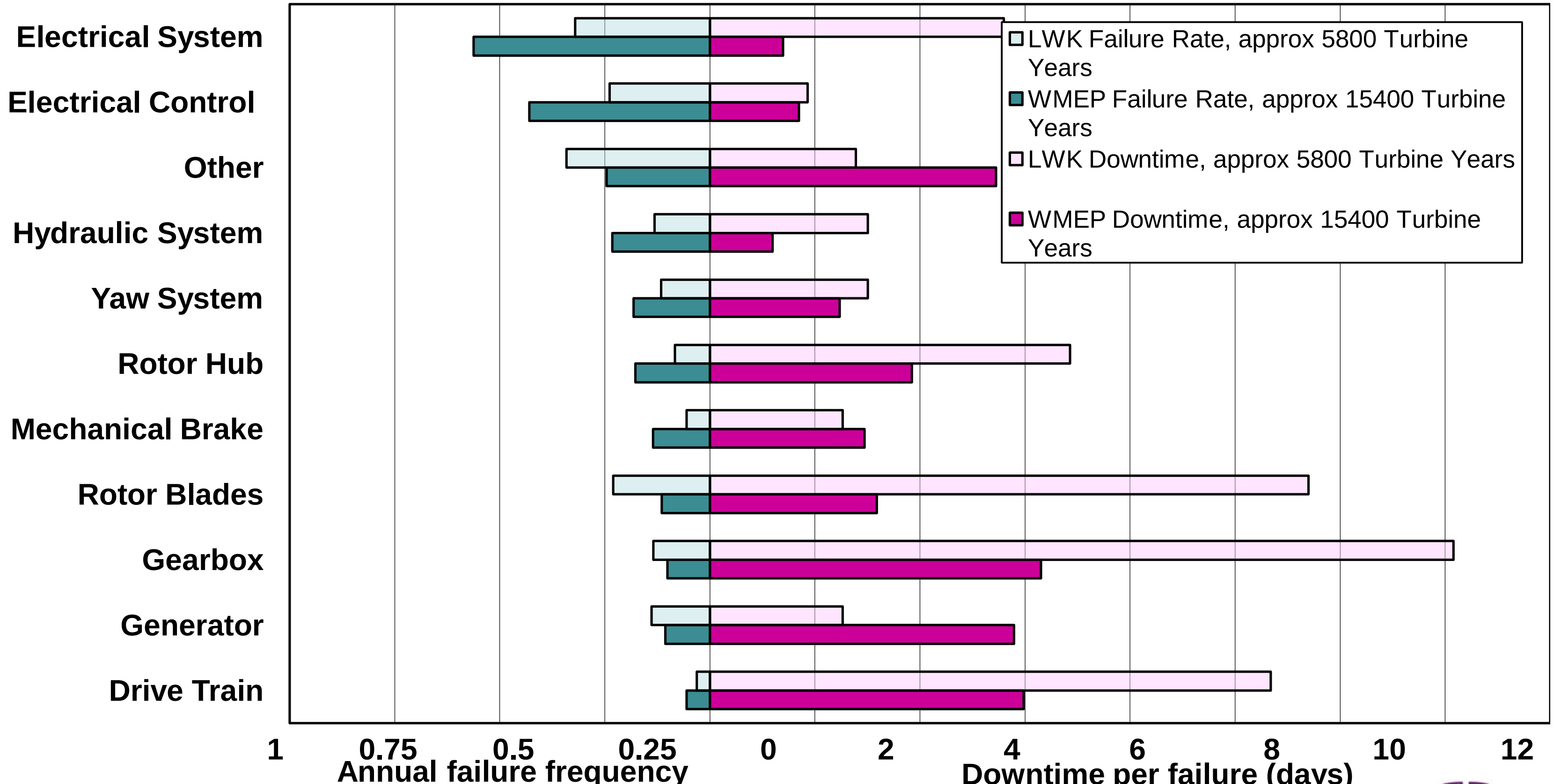
Reliability & Subassemblies Onshore, EU

Failure Rate and Downtime from 2 Large Surveys of onshore European Wind Turbines over 13 years



Overall availability 97%, WT $\lambda_1 =$ 1-3 failures/turbine/year

75% of faults cause 5% of downtime

25% of faults cause 95% of downtime

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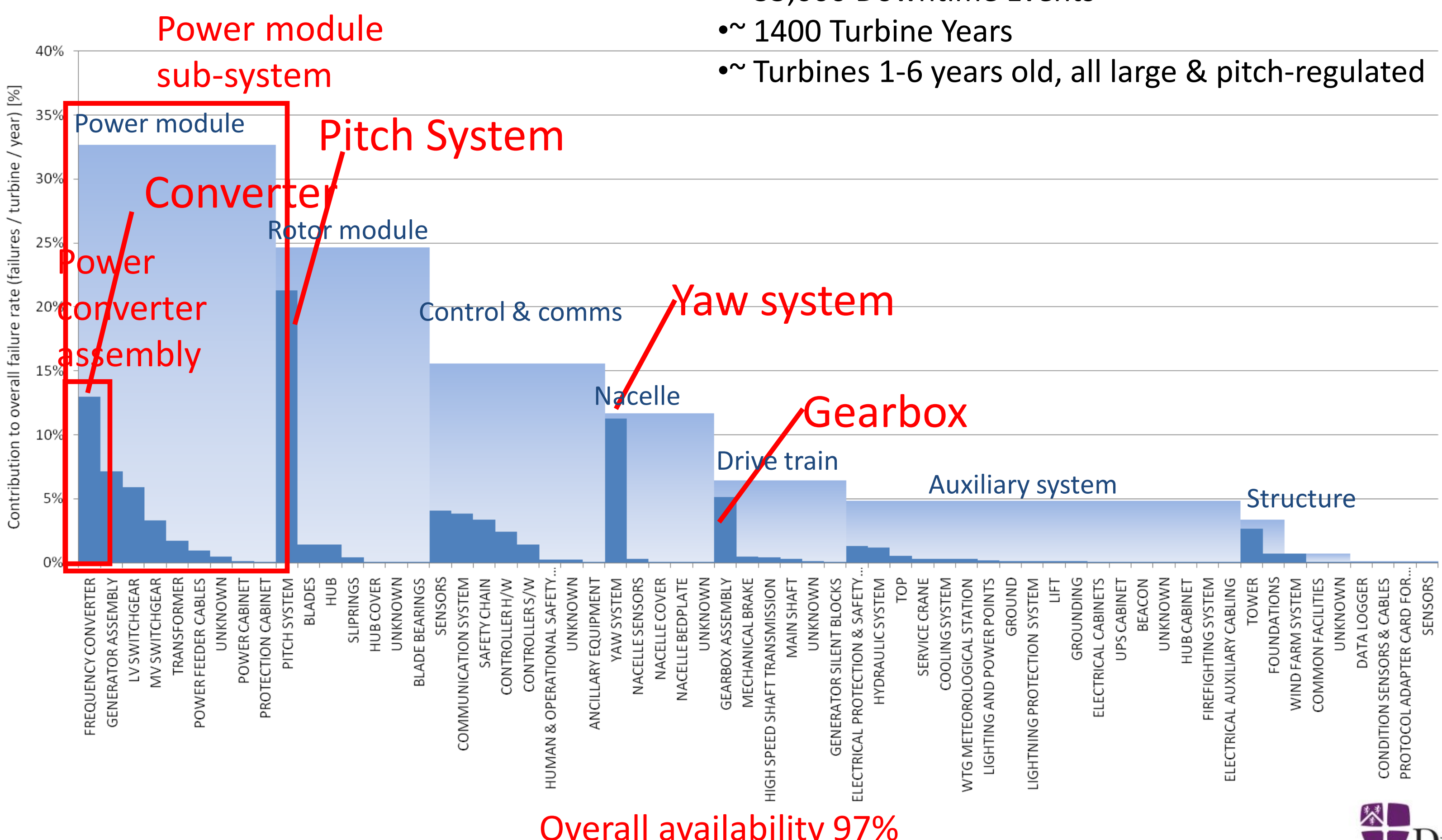
Reliability & Subassemblies Onshore EU

- ~ 35,000 Downtime Events
- ~ 1400 Turbine Years
- ~ Turbines 1-6 years old, all large & pitch-regulated



Percentage contribution to overall failure rate

Data source: turbines from multiple manufacturers

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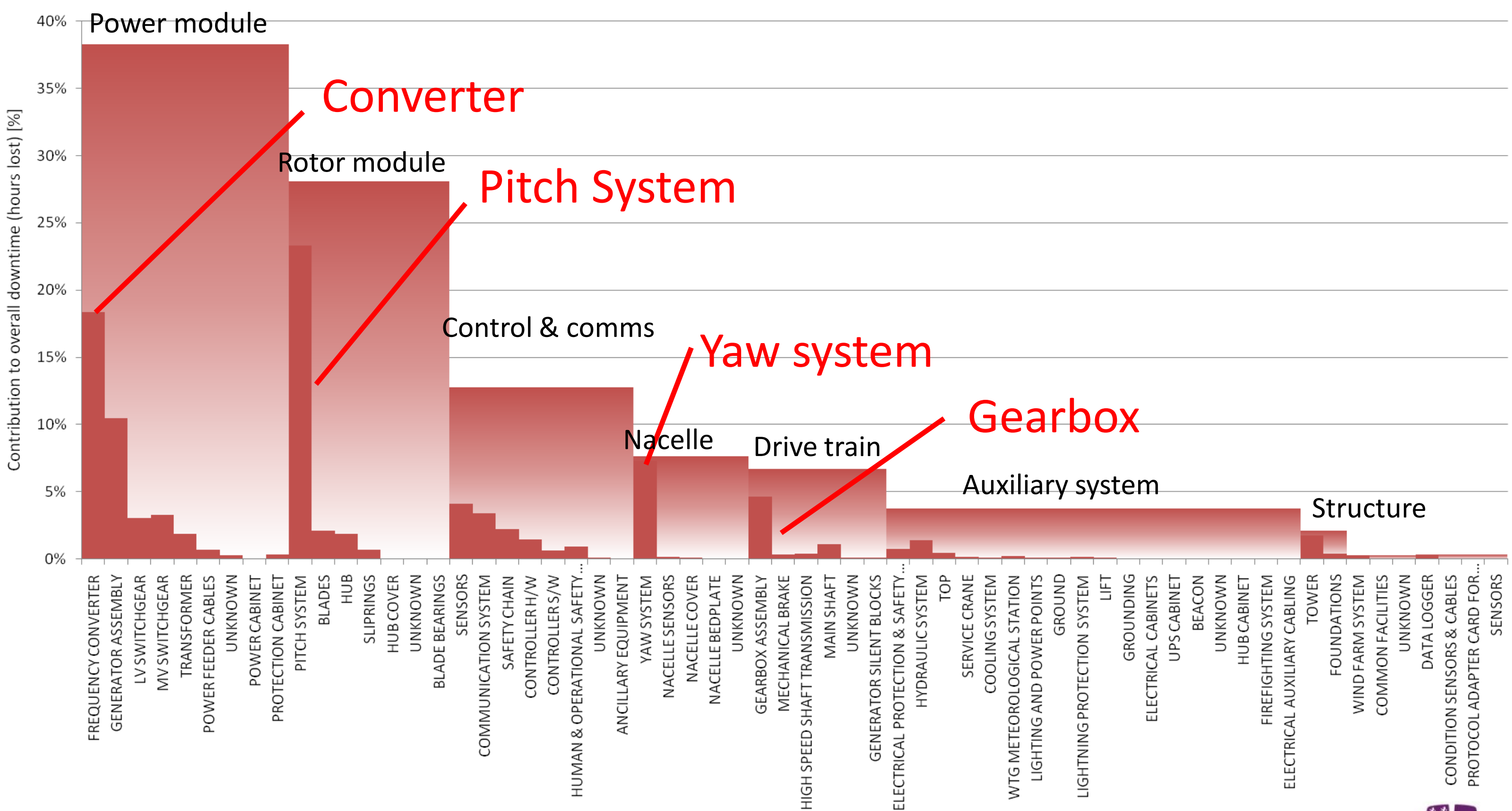
Downtime & Subassemblies Onshore EU



Overall availability 97%

Percentage contribution to overall failure rate

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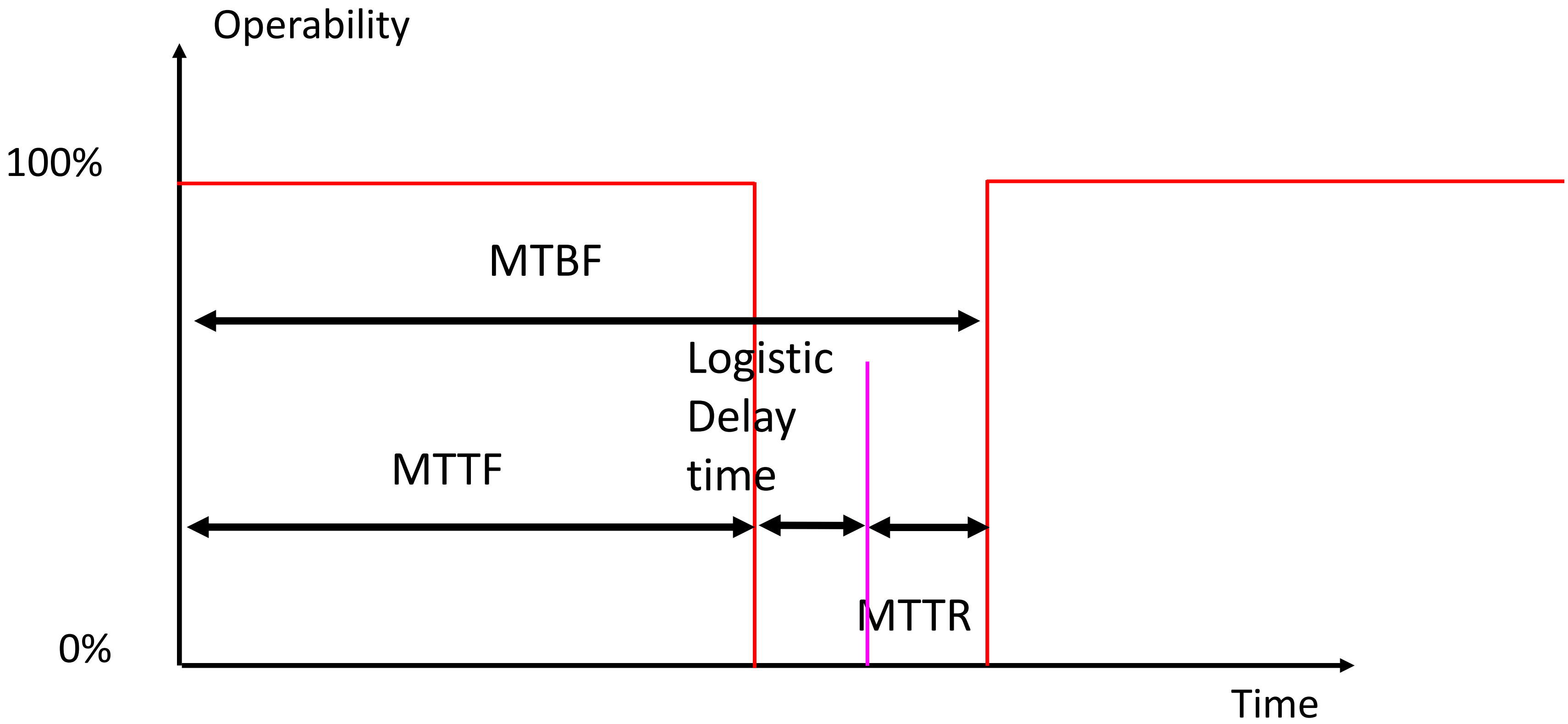
Inherent Availability



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What were the failure criteria?

- Mean Time To Failure — *MTTF*
- Mean Time to Repair, or downtime — *MTTR*
- Mean Time Between Failures — *MTBF*
- WMEP & LWK failure MTTR — > 24hr
- ReliaWind failure MTTR — > 1hr
- Failure rate, λ — $\lambda = 1/MTBF$
- Repair rate, μ — $\mu = 1/MTTR$
- Availability — $A = (MTBF-MTTR)/MTBF$
- $= 1-(\lambda/\mu)$
- If $A=97\%$ in both cases λ depends on μ, which is $1/24$ or $1/1$
- Therefore λ_1=1-3 failures/turbine/yr, λ_2=24-72 failures/turbine/yr

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Summary of ReliaWind WP1 Data: Critical Subassemblies

Sub-system / Assembly	Total Failure Rate %	Medium Time Lost %
Pitch System	16%	20%
Frequency Converter	12%	13%
Yaw System	12%	10%
Control System	14%	9%
Generator Assembly	6%	11%
Gearbox Assembly	5%	4%

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Summary of ReliaWind WP1 & WP2: Critical Subassemblies & Failure Modes

Sub-system / Assembly		Failure Mode 1	Failure Mode 2	Failure Mode 3	Failure Mode 4	Failure Mode 5
Pitch System	Electrical (5 out of 13)	**Battery Failure**	**Pitch Motor Failure**	**Pitch Motor Converter Failure**	**Pitch Bearing Failure**	**Temperature or Humidity Sensor Failure**
	Hydraulic (5 out of 5)	Internal leakage of proportional valve	Internal leakage of solenoid valve	Hydraulic cylinder leakage	Position sensor degraded or no signal	Pressure control valve sensor degraded signal
Frequency Converter (5 out of 18)		**Generator-side or Grid-side Inverter Failure**	**Loss of Generator Speed Signal**	**Crowbar Failure**	**Converter Cooling Failure**	**Control Board Failure**
Yaw System (5 out of 5)		Yaw gearbox & pinion lubrication out of specification	Degraded wind direction signal	Degraded guiding element function	Degraded hydraulic cylinder function	Brake operation valve does not operate
Control System (5 out of 5)		**Temperature sensor modules malfunction**	**PLC analogue input malfunction**	**PLC analogue output malfunction**	**PLC digital input malfunction**	**PLC In Line Controller malfunction**
Generator Assembly (5 out of 11)		Worn slip ring brushes	Stator winding temperature sensor failure	Encoder failure	Bearing failure	External fan failure
Gearbox Assembly (5 out of 5)		**Planetary Gear Failure**	**High Speed Shaft Bearing Failure**	**Intermediate Shaft Bearing Failure**	**Planetary Bearing Failure**	**Lubrication System Malfunction**

Alarm KPIs for 4 Wind Farms

KPIs		Wind Farm 1	Wind Farm 2	Wind Farm 3	Wind Farm 4
Total WT Numbers		30-35			
Ave. Alarm Rate Per 10 min		11	10	10	21
Max. Alarm Rate per 10 min		636	1570	439	541
Percentage of Time Alarm Rates are within these ranges	**0**	24%	19%	20%	7%
	1–10	47%	50%	48%	34%
	11–50	27%	30%	31%	54%
	>51	2%	1%	1%	5%
	In Total	100%	100%	100%	100%

30-35 WTs per Wind farms with each WT having 2-300 I/O
9000 I/O per Wind Farm

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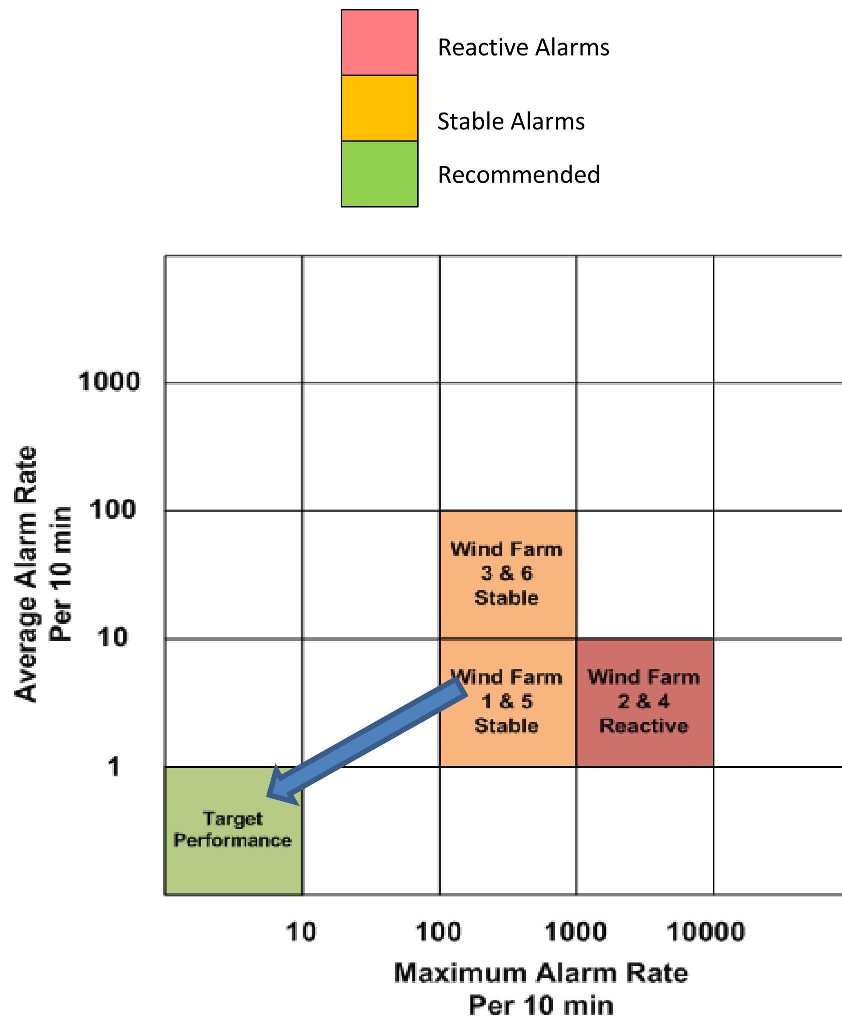
Alarm System Performance Levels

- Matrix for Alarm System Performance Evaluation*
  - **Reactive**: peak alarm rate during upset is unmanageable and alarm system will continue to present an unhelpful distraction to the operator for long period
  - **Stable**: alarms have been well defined for normal operation, but the system is less useful during plant upset



* Alarm systems, a guide to design, management and procurement No. 191 Engineering Equipment and Materials Users Association 1999 ISBN 0 8593 1076 0

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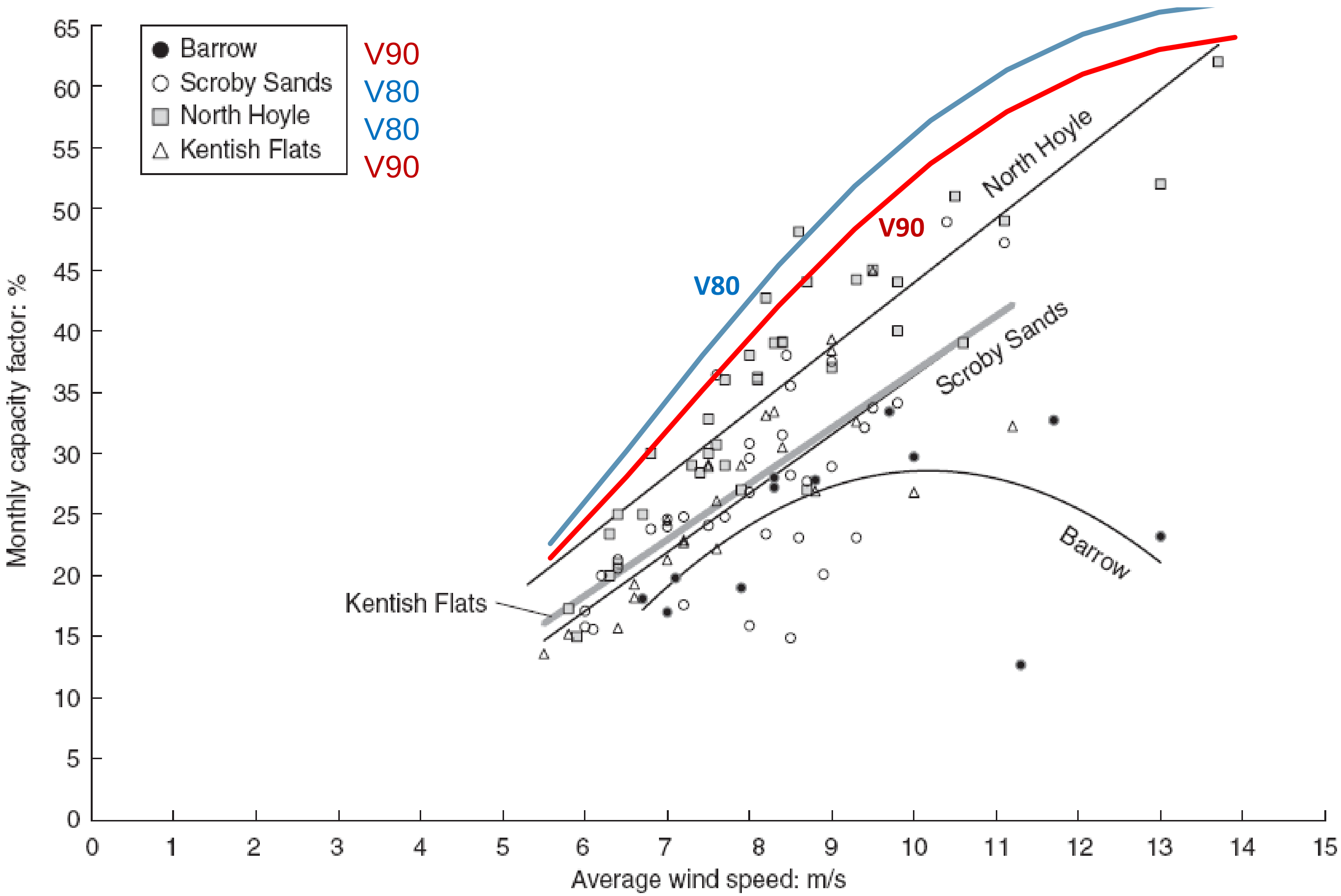
Offshore Capacity Factor & Wind Speed, UK

Monthly capacity factor against wind speed for the offshore wind farms



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Offshore Availability & Wind Speed, UK

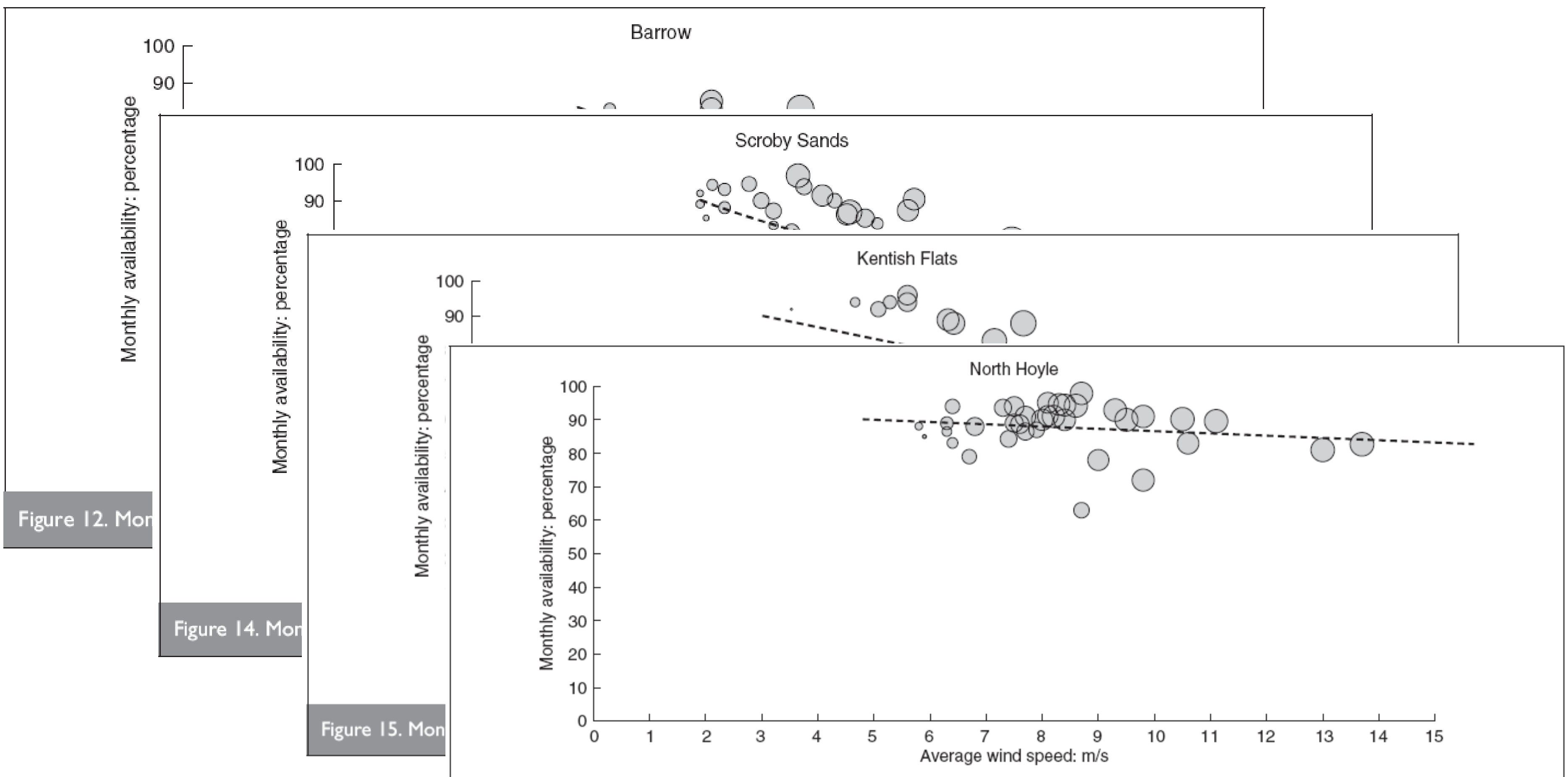
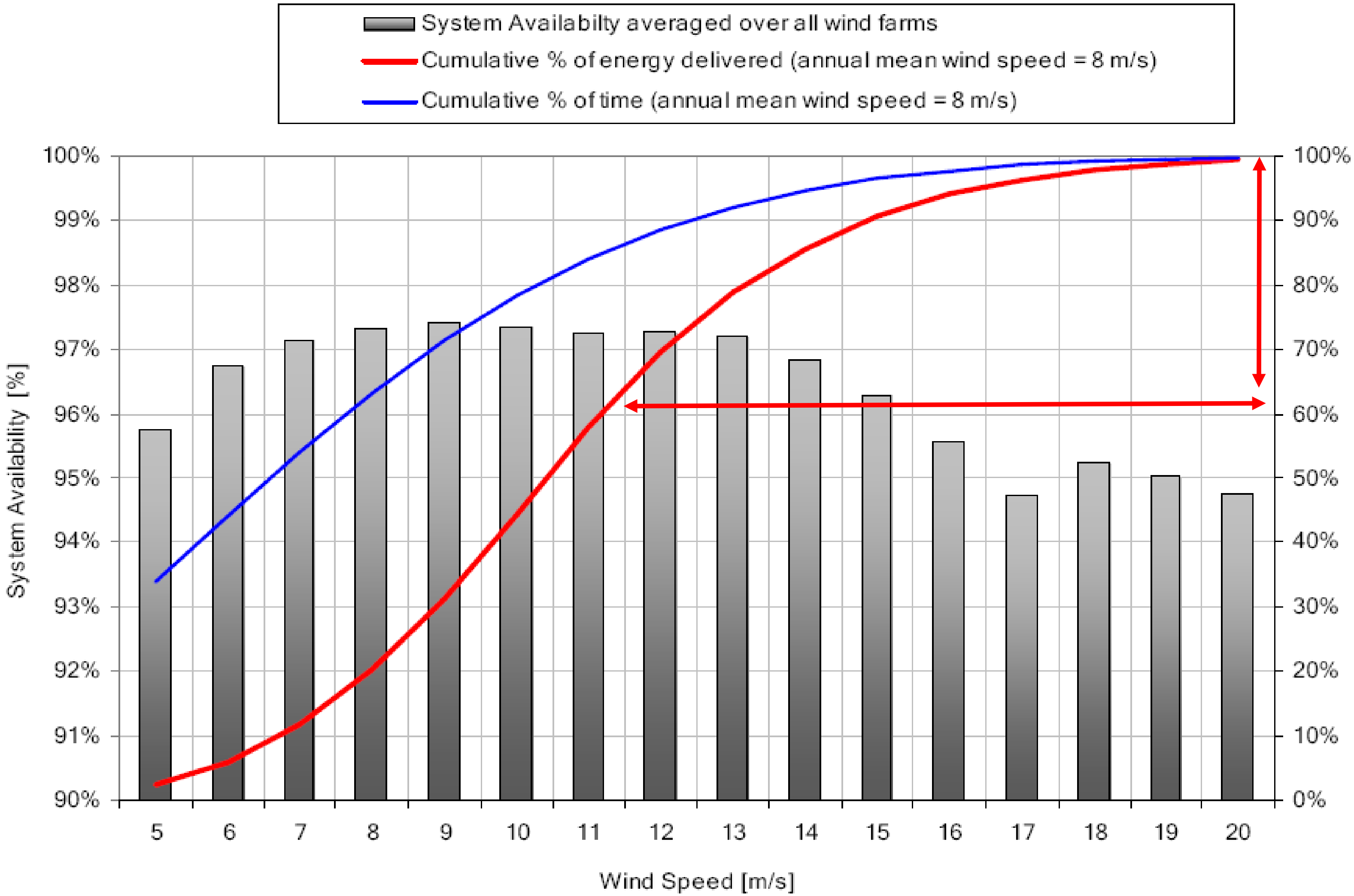


Figure 13. Monthly availability against wind speed for North Hoyle offshore wind farm

Onshore Availability & Wind Speed, World



40% energy produced at wind speeds >11m/s

The Problem:
Offshore Rounds 2 & 3

Wind Farms of 100-500 WTs

400 I/O per WT

20000 WT I/O per Wind Farm

Excluding substation, cables & connection

Total Wind Farm I/O > 30000

Onshore 75% of faults cause 5 % of downtime

Offshore this 75% of small faults will be critical

Because they will consume O&M time & money

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The Solution:
A Wind Farm Knowledge Management System

Integrated SCADA & CMS

Controlled concentration of Wind Farm I/O

Classification of faults per WT

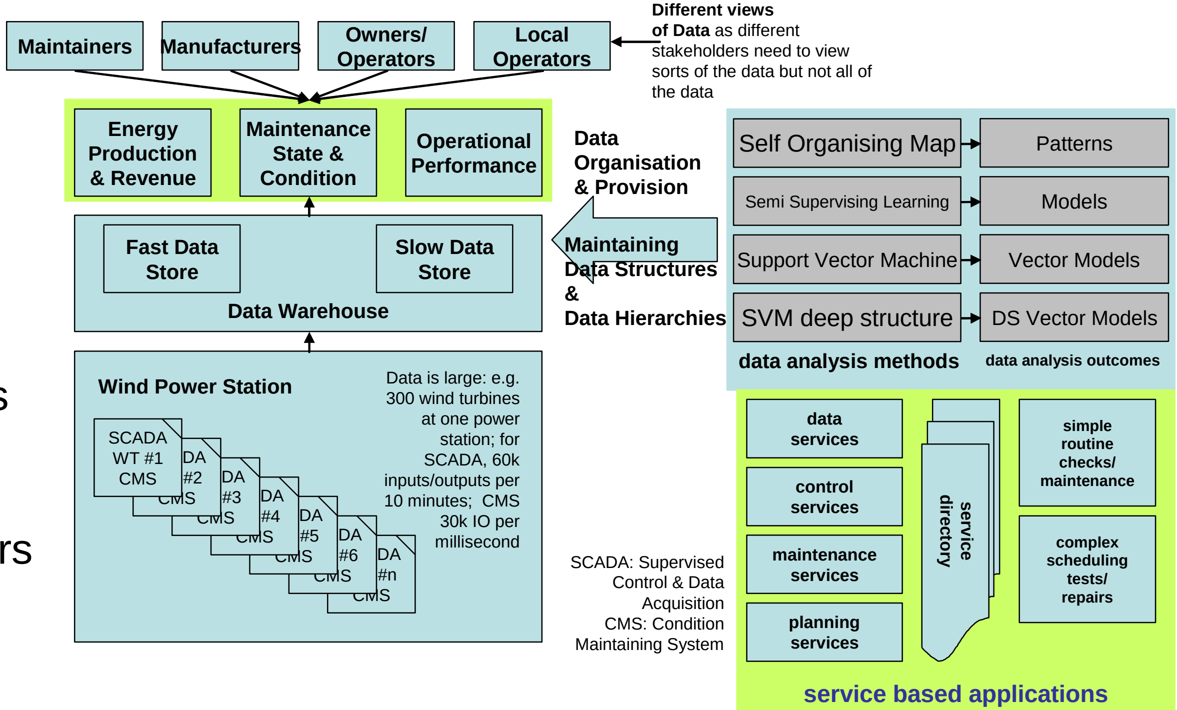
Automatic Alarm Handling

Clear GUI for Operational Managers showing key faults

Clear GUI for Maintenance Managers classifying key faults

Drill down from GUI for Maintainers to diagnose and prognose faults

Lengthen the prognostic horizon



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What issue does this research address?

- **Lack of clarity in SCADA and CMS data**
- **Problem of data overload**
- **Importance of eliminating this problem offshore**

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Impact of this research on the Wind Industry

- **Serious but solvable issue for Offshore Wind Farm O&M**
- **Clear measured failure rate and downtime results to benchmark future developments**
- **Clear methods that could be applied**
- **Clear structure for the future**

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